Using the University of Missouri Grazing Wedge tool to identify patterns in forage management and yield variability in pasture-based farming systems

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Abstract

As we look for agricultural solutions that simultaneously address the growing demand for food and the growing need for sustainability, the potential of grassland agriculture to address both problems should not be overlooked. Grass- and pasture-lands occupy three times the amount of land as row-crop agriculture, while offering significant ecological and economic benefits. Decreasing the forage yield variability of these systems through management techniques has the potential to increase their profitability and popularity. This study looked at how forage information from five farms stored in the University of Missouri Grazing Wedge tool could be used to characterize yield variability in pasture-based farming systems and the types of management practices that might influence that variability. We found that forage yield varied between 6.4 and 33% over the measurement period, and that the variability of total farm yield was largely independent of factors such as forage measurement frequency, interval, and paddock number. Intrapaddock variability, however, is highly correlated with the overall number of paddocks (R-square = 0.83) and offers insight for potential methods for improved management. Going forward, it will be important for these techniques to be incorporated into tools like the Grazing Wedge, and continued investment into these systems will have significant returns.

Introduction

Grassland Agriculture is an important contributor to global food production. Pastures currently cover 3.38 billion hectares of land, which is almost 26% of the earth's surface. In comparison, croplands only cover 1.53 billion hectares, making pasturelands one of the largest uses of land in the world (Foley *et al*., 2011). Nearly all continents have grassland areas devoted to grazing animals, but this type of system is especially important in areas where climatic conditions do not allow for crop production. Pasture production accounts for 55% of beef production in Oceania, 56% and 31% of the milk production from small-ruminants in Sub-Saharan Africa and North Africa (including the Middle East), respectively, and between 25% and 40% of small-ruminant meat production in most regions (Herrero *et al.*, 2013). This type of production is also valuable in regions with resource-poor farmers because it provides them with a well-balance source of nutrition and income to which they would not otherwise have access (Herrero *et al.*, 2013). Additionally, grasses and forages account for 48% of livestock feed globally (Herrero *et al.*, 2013). It is clear then that grasslands and grassland agriculture is an extremely important global resource for food production and food security.

Grasslands are also of economic and agricultural significance in the United States. In 2002, grasslands covered 587 million acres of land, almost 25.9% of the land in the United States (Lubowski *et al.*, 2006). Cropland contributed an additional 442 million acres to the total amount of land devoted to agriculture (Lubowski *et al.*, 2006). While it is generally recognized that the value of grasslands has yet to be fully evaluated (Undersander *et al.*, 2013), there are many indicators that highlight the contributions of grassland. Forages still provide a significant portion of livestock diets, contributing 91%, 83%, and 61% of the total nutrient requirements of sheep, beef cattle, and dairy cattle, respectively (Wilkins and Humphreys, 2003). It is also a low-cost feed source for many livestock producers. Parker *et al*. (1992) showed that pasture-based dairies had profit margins that were \$100-\$150 greater per cow than traditional confinement dairy operations, largely due to reduced feed costs. Rudstrom *et al*. (2005) also showed that the cost of raising heifers was 1.5 times higher in confined feeding operations that in pasture-based operations. Finally, the total production value of "All Hay" in the United States is over 20.2 billion dollars, far surpassing the value of every other crop except corn and soybeans (\$60.2 billion and \$42.2 billion respectively) (National Agricultural Statistics Service, 2014).

Grasslands also have notable environmental value, providing low-cost ecosystems services to every area in which they are located. Grasses and legumes significantly improve soil health through increased organic matter, improved water infiltration, and reduced soil erosion. For example, one experiment in South Dakota saw that fields planted to grass had 0% rainfall runoff and 0 tons of soil erosion per acre, while plowed fields saw 45% of rainfall runoff and erosion rates of 5.6 tons of soil per acre (Lindstrom *et al.*, 1998). An experiment in South Central Texas showed that the soils under grass pasture management contained 38 tons of organic matter per acre and 3000 pounds of microbial biomass per acre, which was much higher than that of the plowed fields which contained 17 tons of organic matter per acre and 1393 pounds of microbial biomass per acre (Franzluebbers *et al.*, 1998). Diverse pasture mixes also increase landscape biodiversity, which provides habitat for beneficial insects such as pollinators and insect predators. This is of special significance as we see the populations of many native pollinators in decline. Another benefit offered by perennial grass planting is improved water quality. The state of New York's highly successful Watershed Protection Program relies heavily on over 460 kilometers of riparian strips and buffer zones to filter water before it enters lakes and rivers (Pires, 2004). As a result, it is one of the only large water supply systems in the United States to be exempted from federal filtration regulations (Pires, 2004). Clearly, grasslands offer not only economic benefit from agricultural production, but they offer many ecosystem services that would be very difficult or expensive to otherwise provide, such as pollination and water filtration.

Despite our improving understanding of the value of these grassland areas, the acreage of these areas in the United States has been gradually declining since the 1950's. There are four general reasons for this. First, horses and draft animals have been replaced by tractors on the large majority of farms. This means that land historically allocated to the production of forage for draft animals is now available for grain production. Second, the amount of land in grass is related to grain prices. Recently, the prices of grain have been very high, incentivizing many farmers to take their land out of forage production or the Conservation Reserve Program (CRP) and plant annual grain crops. Third, the management benefits of including perennial forage species in crop rotations, like weed control or nutrient management, have largely been replaced by inputs. Farmers now have access to affordable herbicides and fertilizers that has limited their need to include grasses and legumes in crop rotations. Lastly, the rations and distribution of livestock have changed to include more grain concentrates fed at distances that are further away from the feed source. Nutrient-dense feeds are less expensive to ship long distances and they shorten the time needed for livestock to reach slaughter weight. All of these factors have contributed to the decline in grassland acreage, but there are currently reasons to expect this acreage will begin expanding once again.

There are multiple reasons why grassland acreage has the potential to expand once more, with much of it being related to consumer demand. First, consumer demand for organic and grass-fed products is increasing. Organic producers are not allowed to use pesticides or herbicides, so they must rely on grasses and legumes to provide for the weed control and nutrient management needs of their crops. The organic food sector happens to be the fastest growing sector of food sales. In 2012, the growth rate of the sector was 7.4%, more than double the rate of growth in every other food sector (Greene, 2013). Organic standards also require that ruminants spend at least a portion of their lives on pasture. The importance of grass and legume plantings will result in increasing grassland acreage as the organic sector continues to grow. The demand for grass-fed animal products has also increased. In response to this demand, the United States Department of Agriculture has very recently (2013) added a new market report that focuses strictly on grass-fed meat products (Morris, 2013). They have also developed grass-fed certification standards, which allows producers to market their meat products as USDA certified Grass-fed (Morris, 2013). Finally, the growing concern of many consumers about the environmental effects of agriculture has led to the introduction of legislation that would regulate non-point sources of agricultural pollution with perennial grass plantings. The Watershed Protection Program in New York is one example of this. Another example is in Minnesota where a bill has been introduced that would require farmers to have 50 foot buffer strips alongside all waterways on their property. All of this interest in organic, grass-fed, and environmentally sustainable agriculture bodes well for the future of grassland and forage plantings.

The economic and environmental benefits of grassland farming warrant improved infrastructure and funding for grasslands research. Despite the fact that grasslands cover a quarter of all the land in the United States and are the third most valuable agricultural crop in the country, only 4% of the research budget of the USDA is allocated toward research for grasses (Undersander *et al*, 2013). The only forage crop with a high-performing private commercial sector is alfalfa, dubbed “the queen of forages” by many in the industry (Undersander *et al.*, 2013). As a result of the limited long-term funding for both private and public breeding programs for forage crops, much of the research has, understandably, been focused on improving grassland management practices. These improvements have included management-intensive (or rotational) grazing, grass-legume interplanting, and nutrient management, among many others. Of specific importance in livestock systems is how these management practices impact yield variability, because this variability impacts stocking rates and feed costs.

One tool that has recently been developed as a management tool for producers is the *Grazing Wedge*, from the University of Missouri Division of Plant Sciences. Designed as a tool to help pasture-based dairies track production and growth, it relies on information provided by the farmer, such as forage height and grazing length, to visually represent the amount of dry matter available as feed. Farmers can opt to have their data included in a public database available to scientists for use in research studies. By taking advantage of this database, this study has three goals. First, we aim to characterize the yield variability experienced by pasture based farmers. Second, , we aim to determine the effects of season length on forage production. Third, we aim to investigate the relationship between yield variability and paddock number, measurement interval, and measurement frequency. These three variables (paddock number, measurement interval, and measurement frequency) are used as a proxy to represent the intensity of management because paddock subdivision and pasture monitoring form the cornerstone of management intensive grazing (Gerrish, 2004; Graffis, Juergenson, McVickar, 1985). We hypothesize that has management intensity increases, the yield variability will decrease.

Materials and Methods

As mentioned above, the data analyzed in this project came from the publicly available "Harvested Yield" tables found on the University of Missouri Grazing Wedge Tool (http://grazingwedge.missouri.edu/). The database includes information from the years of 2006 to 2015, with some years having public information for over 45 different farm entries. Farmers have the option to enter many different types of information, such as livestock class and rotation length, but the only required information needed for each entry is the paddock number and forage yield (measured in pounds per acre). The grazing wedge tool has taken these numbers and calculated the total harvested yield for each farm paddock for each year and listed them in table format. These yield numbers serves as the basis for the experiment.

To identify farms with useful data, three selection criteria were developed. First, chosen farms would need to have at least four years of data. Second, the farms would need to have measurements for at least eight different paddocks. Lastly, these paddocks needed to have yield measurements for at least 90 days over the growing season. If a year was available but had fewer than eight paddocks, it was excluded from the study. Similarly, if paddocks were missing information for any of the four years they were also excluded from the study. The information of the final farms is listed in table one. We assume that the same farms are listed under the same name for each year. We also assume that the paddock names do not change from year to year.

All data analysis was performed using Microsoft Excel. Relationships were tested using linear regression. The average paddock standard deviation was calculated by taking the average of the yearly standard deviations for each paddock by farm. Average farm yield refers to the annual mean amount of forage from all paddocks on one farm. The season length was determined using the first and last available measurement dates, and average season length was calculated by taking the average of the season length for each year.

Results

Farm Characteristics

A total of five farms met the selection criteria as outlined above. The number of years available ranged from four to six, occurring between 2007 and 2014. The number of paddocks ranged from eight for Pogue 1 to 60 for Edgewood Dairy. Indiana Risser has the shortest average season length of 159 days and Rhino has the longest average season length with 242 days. Edgewood Dairy and Rhino were both listed under the “Dairy Milking” livestock class, Pogue 1 was listed under the “Beef Calf/cow” class, and the other two farms have an unknown livestock class (Table 1). Information concerning farm locations, the types of forage grown, management plan, paddock size, and use of irrigation are all unknown.

Table 1: Farm Characteristics

Farm Name	Data Years	Livestock Class	Number of Paddocks	Average Season Length (Days)
Edgewood Dairy	2008, 2009, 2010, 2011	Milking Dairy	60	185
Indiana	2009, 2010, 2011, 2012, 2013, 2014	Unknown	30	175
Indiana Risser	2010, 2011, 2012, 2013, 2014	Unknown	21	159
Pogue 1	2010, 2011, 2012, 2013	Beef Calf/Cow	8	216
Rhino	2007, 2008, 2009, 2010	Milking Dairy	16	242

Forage Yields and Forage Variability

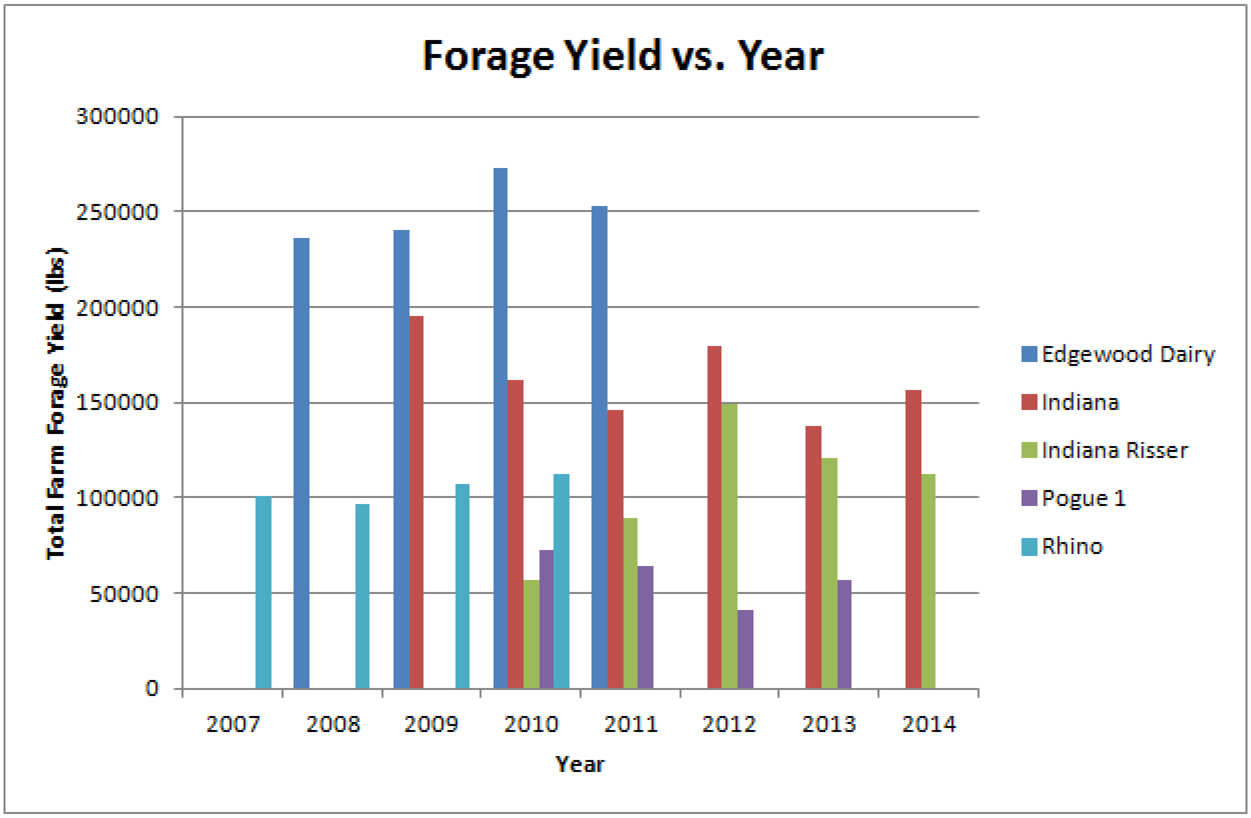
Edgewood Dairy produced the largest amount of forage for each year data was available. The lowest producing farm was Pogue 1 (Figure 1). 2010 was the only year for which all five farms had data, four farms had data for 2011, and three farms had data for 2009, 2012, and 2013 (Table 1). The remaining years (2007, 2008, 2014) had data from only one or two farms. Three farms experienced their maximum forage yields in 2010, while two others, Indiana and Indiana Risser, experienced their maximum forage yields in 2009 and 2012 (Table 2). Minimum forage yields were recorded in 2008 by Edgewood Dairy and Rhino. Indiana Risser recorded the lowest yields in 2010, followed by Pogue 1 in 2012 and Indiana in 2013.

The farm with the lowest yearly paddock forage yield variability was the Edgewood Dairy, with an average standard deviation of 1,008.2 pounds (Table 2). The highest paddock variability, recorded as 2,037.6 pounds by Pogue 1, was over double that amount. Edgewood Dairy also had the highest average forage yield over the recorded period. The value of 250,322 pounds is over 43 short tons higher than the next highest farm, Indiana, which had an average yield value of 162,831 pounds (Table 2). Pogue 1 recorded an average farm yield value of 58,547 pounds, the lowest average of any farm. The total annual forage yields for each farm are shown in Figure 1.

Table 2. Forage Yield and Variability

Farm	Year of maximum forage Yield	Average Paddock Standard Deviation (lbs of forage)	Average Farm Yield (lbs of forage)	Yield per Paddock (lbs of forage)	Farm Yield Standard Deviation (lbs of forage)	Farm Yield Standard Deviation as a Percent of Average Farm Yield (%)
Edgewood Dairy	2010	1,008.2	250,322	4,172	16,274	6.5
Indiana	2009	1,320.5	162,831	5,428	21,103	13.0
Indiana Risser	2012	1,853.6	105,814	5,039	34,884	33.0
Pogue 1	2010	2,037.6	58,547	7,318	13,526	23.1
Rhino	2010	1,597.1	104,110	6,507	6,679	6.4

Figure 1. Total Annual Forage Yield vs. Year



Correlation Models

Figure 2 shows the linear regression for the relationship between the number of paddocks a farm has and the variability in paddock yield. The inverse trend shows that as the number of paddocks increases, the average standard deviation in paddock yield decreases. The R-squared value for the regression is high at 0.83, indicating the trend is compelling.

Figure 3 shows the linear regression for the relationship between the number of paddocks and total farm yield variability, as measured by the standard deviation of total farm yields as a percent of average farm yield. The R-squared value of this regression is 0.24, which indicates the trend is neither compelling nor conclusive.

Table 3 includes the average number of paddock measurements for each farm over all years. Three farms took an average of 17 or 17.5 measurements per season. The Rhino farm took the highest number of forage measurements, with an average of 31.3 measurements per season. Over the course of a season, these numbers resulted in measurement intervals that were between 7.8 and 12.3 days. This means that all of the farms were taking measurements at one to two week intervals.

Figure 4 shows the linear regression for the relationship between the number of measurements taken over the growing season and total farm forage yield variability. There also appears to be a slight inverse trend, but the R-squared value of 0.32 indicates that it is very weak.

Finally, Figure 5 shows the linear regression for the relationship between the length of the growing season and the total annual forage production. The R-squared value of 0.02 indicates that there is no relationship between the two variables.

Figure 2. Paddock Number vs. Paddock Yield

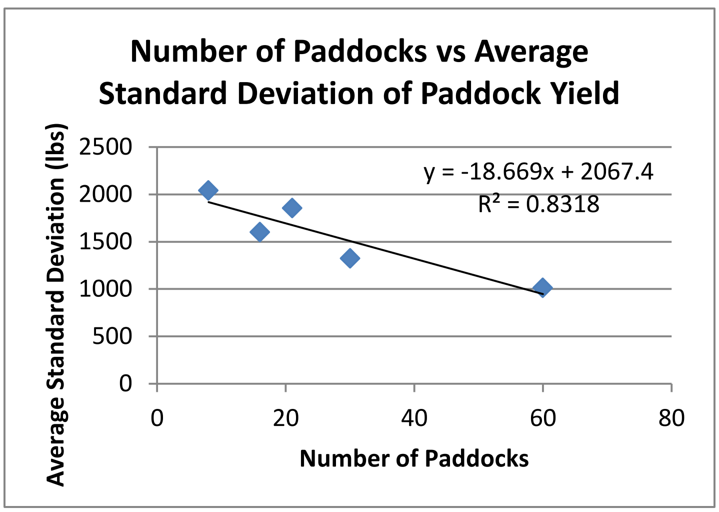


Figure 3. Paddock Number vs. Total Yield Variability

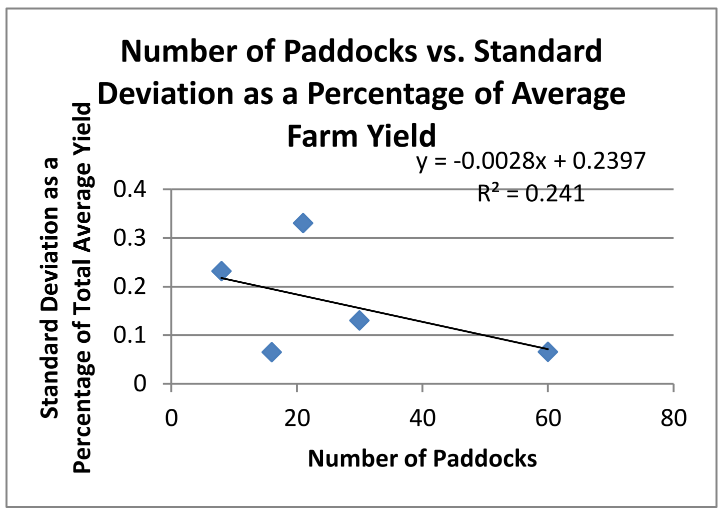


Table 3. Measurement Frequency and Intervals

Farm	Average Number of Paddock Measurements	Average Measurement Interval (Days)
Edgewood Dairy	17	10.9
Indiana	21.8	8.0
Indiana Risser	17	9.3
Pogue 1	17.5	12.3
Rhino	31.3	7.8

Figure 4. Relationship between Measurement Frequency and Farm Yield Variability

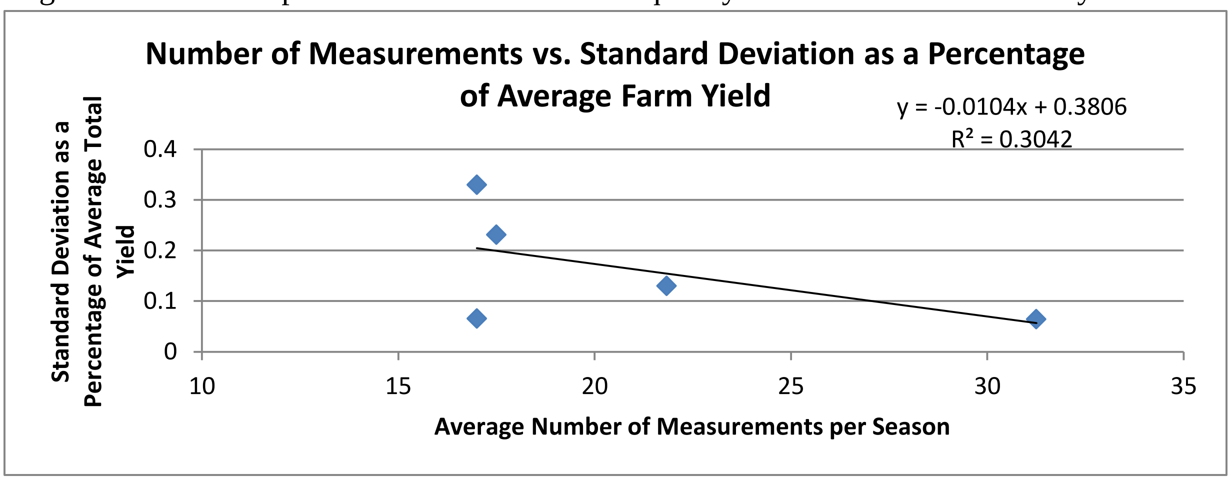
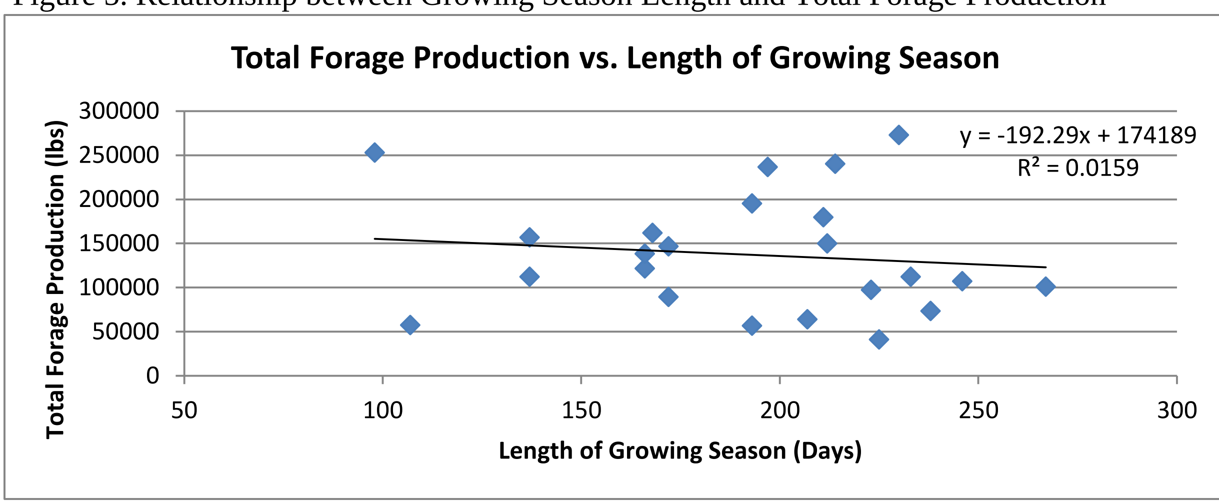


Figure 5. Relationship between Growing Season Length and Total Forage Production



Discussion

Data Characteristics

The Grazing Wedge is a relevant tool because it gives us access to a large amount of real, on-farm data collected by pasture-based farmers. This is extremely useful for trying to understand how different variables relate to forage production outside of controlled experiments. However, there are clear complications that arise with the use of self-reported farm data. First, farmers may employ inconsistent measurement methods. Measurement techniques likely vary by farmer, and each farmer may modify their techniques depending on field conditions and whether or not they have had any formal training on the subject of grass or pasture management. Second, the farmers have the ability to edit data for any measurement for any year. This means that if they have personal reasons to modify data, such as adding an earlier or later date with estimated forage values, they could introduce uncertainty into the data set. Fortunately, the incentive to falsify data is low because users need an accurate grazing wedge in order to manage their pastures appropriately. Overall, any trends that are identified from this data would need to undergo additional evaluation.

Another important aspect of this data collection is that we are comparing farm data collected in different years. It is quite possible that the climate variability from year to year could impact the results of the study, but it is not certain that this effect would be any larger than the effect of other unknown information, such as latitude, location, or presence of irrigation. For example, Edgewood Dairy, Pogue 1, and Rhino all recorded their largest forage crops in 2010, but for the Indiana Risser farm 2010 was actually the year with the lowest yields. Additionally, minimum forage yields were recorded by the five farms across four different years. This indicates that while the yearly conditions may play a role in forage production, there are other factors affecting on-farm forage yield. Because this study seeks to identify general relationships, it is appropriate to consider data from all farms, regardless of the year in which it was taken.

Lastly, it is certain that this study would have benefitted from investigating the results from a larger number of farms with more farm information (use of irrigation, forage species, location, etc), but this information was simply not available to us. As the Grazing Wedge tool continues to collect information, it is likely to accumulate a more robust set of data that would better inform future analyses.

Total Yield Variability

It is clear that yield variability is farm dependent. Indiana Risser had the largest amount of variability, with a total farm standard deviation of 34,884 pounds, which represents 33% of the total average forage yield for that farm (Table 2). This amount variability is not uncommon in forage production systems. In fact, many studies have recorded yearly yield variability as being between 40 and 100% (Mihailović *et al.*, 2006; Greenwood *et al*, 2006).A year-to-year yield variability of nearly a third has huge implications for stocking rates and future production potential, but is not unusual for forage producers. In contrast, the Edgewood Dairy and Rhino farms had much lower variability. Their total farm variability represented 6.5% and 6.4% relative to the mean, respectively (Table 2). This yield variability actually rivals the interannual yield variability of corn grain production in the eastern corn belt, which was around 6-10% between 1930 and 2001 (Kucharik and Ramankutty, 2005). These two farms have little in common besides the fact that they are both classified as Milking Dairy operations (Table 2). The high labor and management requirements of dairy farms could potentially translate to more intensive pasture management, resulting in lower yield variability. Ultimately, these differences in yield variation could be due to a multitude of factors, such as inputs, management, forage type, and climate. However, it is apparent that experiencing more yield consistency will allow farms to take full advantage of their land and production potential.

Influence of Paddock Number

Paddock number varied greatly between farms, from a minimum of eight at Pogue 1 to a maximum of 60 at the Edgewood dairy (Table 1). The Edgewood Dairy farm had double the next highest number of paddocks and also had the lowest interannual paddock yield variability (Table 2). In general, we saw that as the number of paddocks increased, the mean interannual paddock yield variability decreased (Figure 2). Recall that the mean paddock yield variability was calculated by taking the average of the yearly standard deviations for all farm paddocks. One explanation for this trend might be that as the number of paddocks increased, the yield per paddock decreased. We might infer from this that the size of the paddock decreased, resulting in more uniform growth trends across a smaller area. However, with an R-squared value of 0.83, this relationship would benefit from further analysis.

Conversely, the number of paddocks does not seem to affect the variability in total farm forage production (Figure 3). The relationship between paddock number and interannual variability related to the mean is very weak (R-squared = 0.24). Perhaps while decreased paddock size addresses yield irregularity within paddocks, it fails to address the yield variation between paddocks and does little to reduce whole farm variability.

Influence of Measurement Frequency and Interval

Another observation is that there is not a strong relationship between the number of measurements farmers take over the season or the measurement interval and the total farm variability (Figure 4). This may be because the number of measurements is only relevant if they forget to take them near a harvest date. If harvests are taking place and the measurements do not reflect that, then there will be a discrepancy. However, if harvests are occurring at the same rate as measurements are being taken, additional measurements will not reflect total forage yield any more accurately. We might have assumed that increasing the number of measurements would decrease variability, but this is not the case, indicating that producers are adequately monitoring their pastures with weekly or biweekly measurement schedules.

Season Length and Forage Production

Lastly, somewhat surprisingly, there is no relationship between the total length of the growing season and the total annual forage yield (Figure 5, R-squared = 0.02) . There are two potential explanations for this. First, the growing season length was based on the first and last available measurement dates. It is possible that these measurements were taken before or after the growing season actually begins or ends, based on the number of actual growing degree days. Therefore, expanding measurements into this time period doesn't actually relate to additional forage growth. An alternate method for defining the season length would be to look at each year to determine when the first and last harvests are made, and base season length on those dates. A second potential explanation is that we have no information about the location of these farms, so it is possible that variations in climate and growing conditions have resulted in different crop production potentials. In this case, it would be interesting to investigate whether a pattern of countergradient variation (faster growth at higher latitudes) is applicable to forages or not (Geber and Eckhardt, 2005). If this relationship did exist, it would help educate producers about focusing management during specific periods of time in the growing season, especially if they are located at higher latitudes.

Conclusion

In conclusion, the variability in interannual forage yield still plagues producers. This study showed that yields of producers can vary by as much as 33% from one year to the next. However, it also showed that there are producers who have much lower levels of interannual yield variability. Identifying the practices these successful producers have in place may help other farmers improve their yields, and ultimately increase the productivity of grassland agriculture. Additionally, it appears that paddock number does appear to decrease some aspects of yield variability, while the frequency and interval of forage measurements do not. Because both of these factors were both used as a proxy for management intensity, they both support and disprove hypothesis that increasing management intensity will decrease yield variability. Going forward, these factors and their potential effects on yield variability should be addressed separately.

Areas for future research might include approaching farmers who have low forage yield variability and attempting to identify management practices they implement. Similarly, a more focused study on the impact of paddock number and size on variability would clarify the extent of this impact. Continuing to investigate potential pasture management techniques will have important implications for local and international food production and the economic and environmental sustainability of modern agricultural systems.

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